The timing of capacity expansions as barriers to mobility in the United Kingdom's petroleum refining industry between 1948 and 1998

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ABSTRACT

We try to determine whether capacity expansion timing in oligopoly among incumbents can be considered mobility deterring. We study the United Kingdom ´s petroleum refining industry between 1948 and 1998. Using tobit models, evidence is conclusive about accommodation among incumbents. We infer that excess capacity in this industry, instead of being a tool for strategic deterrence, has been the result of unexpected demand variability.

Author Keywords: Capacity expansion timing; Mobility deterrence

JEL Classification: L11; L13; L71

Introduction

The aim of the following paper is to determine whether Capacity Expansion (CE) timing among incumbents in a particular oligopoly market can be considered mobility deterring. While we will speak generally of high fixed-cost industries, due to research interests, we focus on the Petroleum refining industry.

The results obtained signal the importance of allowing for demand uncertainty to time CEs when firms compete in CE projects. This is revealed by this paper's analysis,

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where demand is assumed to be known with certainty. Besides, the frequent episodes of excess capacity make the petroleum refining industry an appealing case to study the interrelation between strategic and non-strategic factors in CE timing.

We test for the timing of CEs as mobility barriers. The U.K.´s petroleum-refining industry is our case study. Surprisingly against the background, our results do not support the hypotheses that incumbents timed CE investments to deter each others during the period 1948-1998.

Observe in industries like petroleum refining, due to product homogeneity, demand shocks usually happen at aggregate level. Since capital equipment is specific to this industry, the costs of CEs tend to be irreversibly sunk, thus (very) expensive commitments are generated when CEs are made.

According to the models we test, incumbent firms in the U.K.´s petroleum-refining industry committed resources when they expanded capacity during 1948-1998 because they tried to use every unit of capacity added. On the other hand, our results show that excess capacity was primarily a consequence of demand variability. In fact, we show that excess capacity emerged as a consequence of unexpected demand shocks.

Hitherto, timing issues when testing CEs as strategic tools among incumbents have been taken up tangentially (e.g., Lieberman [1987a, b] and Gilbert and Lieberman [1987]). For instance, the mentioned articles study investment rivalry across the same sample of U.S. chemical processes industries (between twenty-four and thirty-nine industries), during two decades[1].

[1] When we assert that Lieberman [1987a,b] and Gilbert and Lieberman [1987] treat timing tangentially, we are asserting that these articles are not testing models where time is the decision variable. Rather, they

Amongst these articles, Lieberman [1987b] tests excess capacity as a barrier to mobility by estimating qualitative dependent variable models. There, the timing of CEs is analysed through pre-emptive strategies. While Lieberman searches for evidence on the use of excess capacity as a mobility barrier, he simultaneously studies whether incumbents tend to do anticipatory expansions. He does so by comparing CEs between incumbents and entrants and amongst incumbents themselves; he finds that incumbents tend to time CEs pre-emptively against each other, rather than against entrants.

In this paper we adapt and re-state the models employed in Lieberman [1987b], with the aim of testing for the timing of (strategic) CEs among incumbents in the U.K.´s petroleum refining industry during the period 1948-1998. The timing of (strategic) CEs addressed to entrants is not contemplated in this study.

Hypothesis to test

Capacity built by incumbents after the commencement of entry either through construction of new refineries or additions to existent refineries, may serve mobility deterrence objectives. Moreover, since incumbents have shorter construction leads, they can expand existent refinery facilities more rapidly than for instance an entrant can build a new refinery (usually in a quarter of the time a new refinery takes, that is, in about six months). Excess capacity generated in this way may be equivalent to that of new refineries, but much less costly.

are explicitly proposing an exogenous timing of CEs. The special feature of their models consists, as we will see, of associating a given exogenous timing to the (pricing) models they test.

Then incumbents can employ both refinery construction and incremental capacity to expand output and cut prices when they face other incumbents' CEs. We call this kind of CE mobility deterring, because this can be addressed to deter the growth of existing competitors.

HYPOTHESIS: *If incumbents in the U.K.`s petroleum refining industry have timed CEs to deter the mobility of other incumbents, then they have timed CEs strategically to generate excess capacity through the construction of new refineries and/or the addition of capacity to existing refineries after the commencement of entry.*

Data and variables

As we have already mentioned, our main concern is to analyse mobility barriers, which exist whenever incumbents expand to deter each others' CEs and by definition are feasible only after entry. Here we study CEs addressed at the rest of incumbents, that is, investment after commencement of entry or post-entry investment.

Let K_t be the total industry capacity at the start of year t and be Q_t the total industry output (including refinery fuel) during year t. The average growth rate of the industry in a medium term of three years is defined as

$$g_t = \left[\frac{Q_t}{Q_{t-3}} \right]^{1/3} - 1$$

And the average rate of industry capacity utilisation as

$$U_t = \frac{2Q_t}{K_t + K_{t+1}}$$

Note capacity data are observed as stocks at the beginning of each year, while output data are flows over the course of the year. Post-entry CEs (CEs after commencement of entry) completed during year *t*, are the difference between capacity at the start of year *t* and capacity at the start of year *t+1*.

Expansions of existing plants are usual in petroleum refining. In order to examine mobility barriers, we study investment by incumbents under two forms: Construction of Greenfield refineries and increments upon existent refineries. Entrants, by definition, can invest only in Greenfield refineries. Given that there are lags in the investment process, the actual expansion decision in either case occurs, respectively, during years *t-2* and *t-1*.

We record the impact of industrial concentration levels on (strategic) CEs timing, based on the following Herfindahl-Hirschman index computed at the start of each observation year:

$$CI_t = \sum_i \left(\frac{K_{i,t}}{K_t} \right)^2$$

where $K_{i,t}$ represents the capacity of firm *i* to produce petroleum refining products at the start of year *t*.

Lieberman [1987b] sustains that the change in total industry capacity during year *t* has the following components in post-entry investments:

ΔK_t^E : Greenfield plant capacity completed by entrants;

ΔK_t^I : Greenfield plant capacity completed by incumbents;

ΔK_t^+ : Total incremental expansions of existing plants; and

ΔK_t^- : Capacity shut down

Then the total industry capacity stock at the start of year t is

$$K_t = \sum_{\tau=0}^{t-1} [\Delta K_\tau^E + \Delta K_\tau^I + \Delta K_\tau^+ - \Delta K_\tau^-]$$

Gestation lags for new CEs must be considered. Taking into account these lags, we denote new refinery investment by entrants and incumbents respectively as

$$E_{t-2}^t = \frac{\Delta K_t^E}{K_t} \quad \text{and} \quad I_{t-2}^t = \frac{\Delta K_t^I}{K_t}$$

Where E_{t-2}^t represents the Greenfield refinery capacity initiated by entrants during year *t-2* and completed during year *t*, expressed as a fraction of the capital stock of the industry at the start of year *t* and I_{t-2}^t has the same interpretation for the Greenfield refinery capacity built by incumbents.

In petroleum refining activities, incremental CEs typically have a gestation lag of almost one-year. The rate of incremental CEs by incumbents is therefore:

$$\dot{K}_{t-1}^t = \frac{\Delta K_t^+ - \Delta K_t^-}{K_t}$$

We assume that incremental CEs are perfectly divisible (no lumpiness).

Capacity Expansion Timing and Excess Capacity models

Consider, first, the simple case without entry in which all investment takes the form of incremental CEs on existing refineries by incumbents. For this section, let us assume that demand grows stochastically over time. Incumbents are able to forecast demand and aim to hold an industry capacity stock, $\hat{K}_{t+1}$, at the end of year *t* of:

$$\hat{K}_{t+1} = \beta\left(\frac{Q_t + \hat{Q}_{t+1}}{2}\right) \qquad (1)$$

Where $\hat{Q}_{t+1}$ represents the expected profit maximising output in year *t+1* and *1/β* is its optimal rate of capacity utilisation, which may be a function of capital costs, demand variability, and other factors.

On the other hand, with one-year gestation lag for incremental CEs, the incumbent must forecast future demand in year *t-1* and then take the steps to adjust the capital stock accordingly. The desired rate of investment, $\dot{K}^{*t}_{t-1}$, initiated during year *t-1* and completed during year *t*, which is targeted to reach the desired stock $\hat{K}$ in year *t+1* is

$$\dot{K}^{*t}_{t-1} = \frac{\hat{K}_{t+1} - K_t}{K_t} \qquad (2)$$

If expected annual demand change is $\Delta\hat{Q}$, using (1), we re-write (2) as

$$\dot{K}^{*t}_{t-1} = \beta \frac{Q_t}{K_t} + \beta \frac{\Delta \hat{Q}}{K_t} - \alpha \qquad (3)$$

Thus, the desired incremental CEs in year t can be written as a function of the capacity utilisation *(U)* and the expected rate of demand growth in year *t-1*. We can express this as

$$\dot{K}^{*t}_{t-1} = \alpha + \beta_u U_{t-1} + \beta_g \hat{g}_{t-1} \qquad (4)$$

Empirically, U_{t-1} can be observed, but $\hat{g}_{t-1}$ cannot. We use g_{t-1}, the last year´s average rate of output growth, as a proxy for $\hat{g}_{t-1}$. The true expected rate of growth equals this rate plus an unexpected component $\tilde{g}_{t-1}$, i.e, $\hat{g}_{t-1} = g_{t-1} + \tilde{g}_{t-1}$.

Now consider the case where incumbents' investment may include both Greenfield refineries (*I*) and incremental CEs of existing facilities. Suppose illustratively that firms meet part of their investment needs with Greenfield refineries and then cover the remainder with incremental CEs[2].

Given the lags for Greenfield refinery construction, an investment decision must be made in year *t-2* for the refinery to open in year *t*. In the following year *t-1* incumbents project incremental CEs, such that:

$$\dot{K}^{*t}_{t-1} = \alpha + \beta_U U_{t-1} + \beta_g g_{t-1} + \beta_{\tilde{g}} \tilde{g}_{t-1} + \gamma^I_{t-2} I^t_{t-2} + \gamma^I_{t-1} I^{t+1}_{t-2} \qquad (5)$$

[2] The other way round is also feasible, we do it in this manner just for stating the model.

The parameter γ indicates the extent to which incumbents adjust incremental CEs to accommodate their lumpy new refineries scheduled to open in year *t*. Hence investment has a recursive structure, with new refinery investment initiated in year *t-2*, followed by incremental investment in year *t-1*, both of which will be targeted to reach the desired capacity stock $\hat{K}_{t+1}$ by the end of year *t*.

Let us now expand the model to include investment by entrants, who can invest only in Greenfield refineries (*E*). Therefore, incremental CEs will be estimated through:

$$\dot{K}_{t-1}^{t} = \alpha + \beta_u U_{t-1} + \beta_g g_{t-1} + \gamma_{t-2}^{E} E_{t-2}^{t} + \gamma_{t-2}^{I} I_{t-2}^{t} + \gamma_{t-1}^{E} E_{t-2}^{t+1} + \gamma_{t-1}^{I} I_{t-2}^{t+1} + [\beta_{\tilde{g}} \tilde{g}_{t-1} + e_{t-1}] \quad (6)$$

The dependent variable $\dot{K}_{t-1}^{t}$, denotes the amount of incremental CE in year *t* as a fraction of the total industry capacity at the start of the year. To control for the downward inflexibility of existent refinery capacity, we truncate $\dot{K}_{t-1}^{t}$ at zero for observations where the original value is negative. Thus we treat observations with zero or negative values identically. Consequently, we use tobit analysis to fit equation (6).

Lieberman [1987b] asserts that if the incremental investment is perfectly divisible and flexible both upward and downward, then $\gamma = -1$, i.e., Greenfield refinery investments initiated in year *t-2* are perfectly accommodated through reductions of incremental investments in year *t-1*. We hold that this effect would underscore any mobility-deterrence character of CEs timing, because across the industry incremental CEs may accommodate Greenfield refinery construction.

However, in the same article Lieberman also asserts, in the practice, there are numerous reasons why such a perfect accommodation might fail to occur. With multiple incumbents, information or co-ordination problems may arise[3]. These features of competition interaction would lead to an incomplete accommodation, because incremental investments would not complement Greenfield investments.

Consequently, we could speak of mobility deterrence CE timing if $\gamma > -1$, because across the industry Greenfield refineries would not be accommodated through incremental CEs on existing refineries[4].

Consequently, on equation (6), we test sub-hypotheses

$$1)\ \begin{array}{l} n.s.h: \gamma^{E}_{t-2}, \gamma^{E}_{t-1}, \gamma^{I}_{t-2}, \gamma^{I}_{t-1} = 0 \\ a.s.h: \gamma^{E}_{t-2}, \gamma^{E}_{t-1}, \gamma^{I}_{t-2}, \gamma^{I}_{t-1} \neq 0 \end{array}$$

If sub-hypothesis 1) were rejected, then sub-hypothesis

$$2)\ \begin{array}{l} n.s.h: \gamma^{E}_{t-2}, \gamma^{E}_{t-1}, \gamma^{I}_{t-2}, \gamma^{I}_{t-1} > -1 \\ a.s.h: \gamma^{E}_{t-2}, \gamma^{E}_{t-1}, \gamma^{I}_{t-2}, \gamma^{I}_{t-1} \leq -1 \end{array}$$

should not be rejected for asserting that incumbents in the U.K.´s Petroleum Refining Industry timed incremental CEs with mobility deterring purposes during the period 1948-1998.

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[3] If incremental CEs are lumpy and it is better to be above the target capital than below it, accommodation will be incomplete.

[4] Likewise, an additional feature limiting accommodation is that existing refinery capacity tends to be inflexible downward. Given sunk investment costs, firms in a growing market are unlikely to make permanent refinery closures in response to brief market downturns or temporary over-capacity arising from completion of lumpy new refineries. In other words, $\dot{K}^{*_t}_{t-1}$ will seldom be negative. In any case, as we mentioned above, the problem can be coped with econometrically by treating observations with zero or negative net investment identically using tobit analysis.

On the other hand, for our industry we define excess capacity as the difference between the capacity that minimises the average total costs of any refinery and its actual capacity. In order to test our hypothesis, we analyse the creation of excess capacity after commencement of entry to match it to the outcomes of the model in equation (6).

Let us suppose that Q_t is produced at the minimum average total costs. It is necessary to remark that refineries are usually closed for maintenance between 18 and 36 days a year. Consequently, we choose a threshold of 7.5% capacity "surplus" for determining the existence of excess capacity properly speaking. Therefore, summing across refineries, we compute excess capacity at industry level S_t for each observation year as:

$$S_t = \begin{cases} \dfrac{K_t - Q_t}{K_t} & \text{if} \quad S > 0.075 \\ 0 & \text{Otherwise} \end{cases} \tag{7}$$

Also following Lieberman´s [1987b] definitions, a second measure of excess capacity, $S_t^{'}$, is computed, but adjusting for differences in new capacity lumpiness.

When capacity is lumpy, even with perfect co-ordination firms might hold excess "lumps" for non-deterring reasons. Hence, in order to correct for this, to compute $S_t^{'}$, we omit from K_t the largest capacity increment added during the prior three years or during the most recent year of investment, if no expansion occurred during the prior three-year period, that is,

$$S_t^{'} = \begin{cases} \text{As in (7), but omitting the largest capacity increment added during the prior three years or during the most recent year of investment if no expansion occurred during prior three-year period} & \text{if} \quad S^{'} > 0.075 \\ 0 & \text{Otherwise} \end{cases} \tag{8}$$

Lieberman [1987b] points out that profit-maximising firms hold non-deterrence aimed excess capacity in markets where demand is cyclical or stochastic, or where refineries are inherently lumpy or subject to economies of scale. Optimal idle capacity increases with demand variability under a range of structural conditions, going from perfect competition to monopoly.

He adds that if refineries are lumpy, temporary excess capacity normally arises after new refineries are constructed, particularly if prices are not completely flexible. If more than one production technology is available, low variable but high fixed costs refineries may be held in reserve to serve periods of peak demand. According to him, the dependent variable $S_t^{'}$ corrects for such lumpiness. Then, construction of new refineries and/or additions on existent refineries has a lagged effect (if any).

For our hypothesis not to be rejected, we need to find statistically significant positive coefficients with respect to variables (7) and (8) models in relation to the incumbents-induced CE variables CI_t , I_{t-2}^{t} and $\dot{K}_{t-1}^{t}$. Below we include additional control variables to account for excess capacity held for non-mobility deterrence reasons. E_{t-2}^{t} is expected to increase excess capacity, but without any strategic consequence. With (S_t) and without ($S_t^{'}$) lumpiness effects tobit regressions are used.

In the estimation of indicators (7) and (8) we include σ_t, the standard deviation of year-to-year rates of output growth from *t-5* to *t* for petroleum refining products. This measure should point out excess capacity held to accommodate the demand variability of petroleum refining products in the U.K. over the period 1948-1998. We also include the time trend *t* to capture the impact of possible time-related factors on excess capacity. Both variables, σ_t and t , are expected not to have statistically significant positive coefficients in the models of (7) and (8) for our hypothesis not to be rejected.

Note in the following models we add to Lieberman [1987b]'s, providing a more complete explanation of post-entry excess capacity by specifying incremental CEs as an explanatory variable. In particular, we fit

$$S_t = j_0 + j_1 t + j_2 \sigma_t + j_3 CI_t + j_4 \dot{K}_{t-1}^{t-2} + j_5 I_{t-2}^{t-2} + e_t \quad (9)$$

Testing

3) $\begin{matrix} n.s.h: j_1, j_2 \leq 0 \\ a.s.h: j_1, j_2 > 0 \end{matrix}$ 4) $\begin{matrix} n.s.h: j_3 \geq 0 \\ a.s.h: j_3 < 0 \end{matrix}$ 5) $\begin{matrix} n.s.h: j_4, j_5 \geq 0 \\ a.s.h: j_4, j_5 < 0 \end{matrix}$

And

$$S_t^{'} = l_0 + l_1 t + l_2 \sigma_t + l_3 CI_t + l_4 \dot{K}_{t-1}^{t-2} + l_5 I_{t-2}^{t-2} + e_t \quad (10)$$

Testing

6) $\begin{matrix} n.s.h: l_1, l_2 \leq 0 \\ a.s.h: l_1, l_2 > 0 \end{matrix}$ 7) $\begin{matrix} n.s.h: l_3 \geq 0 \\ a.s.h: l_3 < 0 \end{matrix}$ 8) $\begin{matrix} n.s.h: l_4, l_5 \geq 0 \\ a.s.h: l_4, l_5 < 0 \end{matrix}$

Analysis of Results

Lack of convergence, likely due to the low number of uncensored observations (only 41% of changes in the total industry capacity stock corresponded to incremental CEs), makes us re-specify the model in equation (6). This leaves us then with a quite similar version of equation (6) that permits us to test sub-hypotheses 1) and 2), to know:

$$\dot{K}_{t-1}^{t} = \alpha + \beta_{u-1}U_{t-1} + \beta_{g-1}g_{t-1} + \gamma_{t-1}^{E}E_{t-2}^{t+1} + \gamma_{t-3}^{E}E_{t-2}^{t-1} + \gamma_{t-1}^{I}I_{t-2}^{t+1} + \gamma_{t-2}^{I}I_{t-2}^{t} \qquad (6')$$

Note that testing sub-hypotheses 1) and 2) would not be possible with the original specification of equation (6). In the tobit fit of equation (6´) convergence is achieved. The model in table 1 is overall significant and well specified at a 5.00% significance level. Based upon this, at a 5.00% significance level too, we cannot reject sub-hypothesis 1) nor sub-hypothesis 2), except with respect to γ_{t-2}^{I}. After a Wald test, we can reject sub-hypothesis 2) with respect to γ_{t-2}^{I} only.

Therefore, results in table 1 show that incumbents' incremental CEs in the U.K.'s petroleum refining industry during 1948-1998 were not influenced by entrants' Greenfield refineries. Instead incumbents pursued the substitution of their own Greenfield refinery capacity when they timed incremental CEs.

According to this Tobit model, for each tonne of crude processing capacity added through their new refineries, incumbents diminished incremental CEs on existent refineries approximately 1.12 tonnes. Hence, we can hold incumbents during 1948-1998 did not time incremental CEs in their already existent refineries in order to deter mobility of other incumbents.

We infer that incumbents timed incremental CEs with the objective of substituting their Greenfield refinery capacity, instead of deterring each others´ CEs.

On the other hand, in table 2 we get the impact of incremental CEs on existent refineries excess capacity. In this table, the models of equations (9) and (10) are significant and well specified tobit regressions. We reject the null sub-hypothesis in 3) for j_2 but not for j_1; we reject the null sub-hypothesis in 4); and we reject the null sub-hypothesis in 5) for j_4 but not for j_5, which is not significant.

With lumpiness effects in the estimation of equation (9) in table 2, observe a rise of 1.00% in incremental CEs on existent refineries in year *t-2* reduced excess capacity in year *t* 0.19%, which is contrary to the expected in our hypothesis. However, this aligns with the finding on the model of equation (6`), according to which, incumbents timed incremental CEs with the objective of substituting Greenfield refinery capacity, as they tried to over-utilise each additional capacity they installed on existent refineries.

Besides, when lumpiness effects are considered in table 2, for each 1.00% increase in the industrial concentration index, excess capacity diminished 5.22%, and for each 1.00% increment of demand variability excess capacity increased 1.25%. Additionally, excess capacity tended to diminish 0.022% during 1948-1998 with lumpiness effects.

We reject the null sub-hypothesis in 6) for l_2 but not for l_1, which is not significant; we reject the null sub-hypothesis in 7); and we do not reject the null sub-hypothesis in 8) because none coefficient is significant. Without lumpiness effects in the estimation of equation (10) in table 2, for each 1.00% increase in the industrial concentration index, excess capacity diminished 5.21%, and for each 1.00% increment of demand variability excess capacity increased 1.83%.

Although incremental CEs on existent refineries only are significant on excess capacity when lumpiness is accounted for, observe without lumpiness effects demand variability generates 46.4% more excess capacity than with lumpiness effects if incremental CEs on existent refineries are specified, which shows the relevance of this non entry/mobility deterrence variable, because it is shown that demand variability raised excess capacity after ruling out for explicit non-deterring aimed excess capacity.

Conclusions

We can state that incumbents were willing to commit themselves to use capacity fully when they added capacity to existent refineries after commencement of entry, since they tended to over-utilise them. This is meaningful in an industry where capacity costs are irreversible and sunk such that capacity is indeed costly.

In this paper we have shown that even excess capacity that was intended to be strategic was generated by demand variability. The inclusion of incremental CEs strengthens these findings. We conclude that excess capacity was mainly a result of demand variability in post-entry CEs during 1948-1998 in the U.K.´s Petroleum Refining Industry, because incumbents did not use it as a mobility deterring tool.

Consequently, we reject our hypothesis, because excess capacity was not generated with mobility deterring purposes, and incumbents timed incremental CEs to accommodate each other’s Greenfield refineries. Observe demand variability is now playing a crucial role not contemplated before.

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	$\dot{K}_{t-1}^{t}$
cons	0.7712628 (0.053)
U_{t-1}	0.2085432 (0.606)
g_{t-1}	-0.0458184 (0.870)
E_{t-2}^{t-1}	-0.2285983 (0.305)
E_{t-2}^{t+1}	-0.2272634 (0.304)
I_{t-2}^{t+1}	0.0697457 (0.761)
I_{t-2}^{t}	-1.117069 (0.000)
Log likelihood	19.057978
Number of obs	21
LR χ^2	23.88*
Prob > χ^2	**0.0005**
P>|t| of hatsq	**0.302**

*Six d.o.f

Table 1. Incremental Capacity Expansions Model

	cons	t	σ_t	CI_t	$\dot{K}_{t-1}^{t-2}$	I_{t-2}^{t-2}
S_t	1.727185	-0.0217009	1.251207	-5.218529	-0.1906488	-0.3734054
	(0.002)	(0.017)	(0.026)	(0.003)	(0.101)	(0.291)
S'_t	1.551195	-0.0183368	1.83078	-5.214304	-0.2308034	-0.4303065
	(0.026)	(0.113)	(0.036)	(0.034)	(0.112)	(0.336)

S_t ***ESTIMATES:***		S'_t ***ESTIMATES:***	
Log likelihood	**6.3358886**	Log likelihood	**-0.5285867**
Number of obs	30	Number of obs	30
LR $\chi^2(5)$	25.51	LR $\chi^2(5)$	16.93
Prob > $\chi^2(5)$	**0.0001**	Prob > $\chi^2(5)$	**0.0046**
P>|t| of hatsq	**0.883**	P>|t| of hatsq	**0.525**

Table 2. Excess Capacity with incremental Capacity Expansions